Comparative Analysis of Inspection and Diagnosis Tools for Ancient Buildings

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Abstract. The survey and inspection of the state of conservation of buildings is understood as an active process of selecting information to support decision making in the rehabilitation of the built heritage. The development of new technologies applied to the integrated management of the built heritage resulted in digital tools able to support the technicians in on-site procedures. The purpose of this study was to analyse existing methods for the survey and inspection of the state of conservation of ancient buildings. It uses a qualitative methodology, focused on bibliographical survey and comparative analysis. Only methods with identical characteristics were considered: evaluation based on visual inspection of buildings with heritage value. This research shows that structuring information in computer systems is a solution to overcome the main problems pointed out in previous studies related to survey and inspection: expensive, time-consuming, inconsequential procedures and dispersed information. However, this is only valid if computer-based methods are adapted to the different geographic and chronological contexts. Future research may contribute to the development of a method that brings together this added value with a simple but objective way to diagnose the condition of ancient buildings with heritage value.

Keywords: Built heritage · Inspection · Digital tools

1 Introduction

In the recent history of built heritage preservation, there is a constant concern to understand the building, through historical analysis and state of conservation assessment [1–6]. The evolution of this concept has essentially two vectors: the extension of the concept of heritage to groups of buildings and historic districts [7–9]; and the technological progress, which introduces new tools that empower management and design processes.

The "principles for the analysis, conservation and structural restoration of architectural heritage" [6] are aimed at ensuring "rational methods of analysis and repair methods appropriate to the cultural context" [6]. This document recommends diagnosis based on qualitative approaches, i.e. historical information, direct observation, but also quantitative, through trials and monitoring. However, the principles are not enough to support practitioner's decisions and imply the use of complementary resources.

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New technologies have followed the need to gather more information about the building, such as: the use of laser scanner and photogrammetry for detailed survey of historical buildings [10, 11], the non-destructive analysis of old structures through digital images and thermography [12], and the development of methodologies for the transposition of data collected to parameterized three-dimensional models [13]. All these studies confirm the survey as an active process, essential for supported decision-making. However, they are mostly oriented to interventions in monuments. Considering the need to "establish a cost-effective plan of activities proportional to the structure's complexity and which also takes into account the real benefit to be obtained from the knowledge gained" [6], such methods are usually not suitable for smaller buildings, such as historic dwellings of private owners.

A survey to practitioners in Portugal [14] concluded that, in the renovation of residential buildings, there is low budget and time available to resort to current detailed methods of inspection and diagnosis. This problem is aggravated by the scarcity of technical information and its dispersion. Only 74% of the respondents perform regular inspection of the state of conservation in this type of buildings. However the procedures used lack objectivity since they are based on photographic record and on previous experiences.

This research presents a comparative analysis of international methods to support inspection and diagnosis procedures in heritage buildings. The focus is to systematize their characteristics and identify the potential of their application in professional practice according to the needs expressed by practitioners in previous studies, e.g. [14, 15].

2 Methodology

This research uses a qualitative methodology, focused on bibliographical survey and comparative analysis of methods used in Portugal and internationally.

In the literature review, the tools were selected considering three criteria:

(a) Tools most used in professional practice by technicians in Portugal [14];
(b) Prominent tools in international scientific literature;
(c) International tools aimed at practical conservation.

For each assessment criterion, two tools were considered. Only methods that have identical characteristics were considered: evaluation based on visual inspection and focus on buildings with heritage value. Thus, expert-systems not oriented towards heritage rehabilitation [16], or that have already been the subject of previous studies [17], were excluded.

The key variables considered in the comparative analysis were: support (type of storage by which information is communicated); format (structure for processing and displaying the data); type of buildings, end-user, and stage of the intervention; and outputs (type of results obtained).

3 Tools to Support Building Inspections and Diagnosis

3.1 Brief Description

This section presents the characterization of the analysed tools, as described in Table 1, contextualizing their scope and aim.

Table 1. Inspection and diagnosis support tools analysed.

Source	Tool	Country	Author	Year
Identified by Portuguese professionals	Reabilitação de Edifícios Antigos (REA)	Portugal	Appleton	2003–2011
	Método de Avaliação do Estado de Conservação de Imóveis (MAEC)	Portugal	LNEC	2007
Scientific literature	Monument Diagnosis and Conservation System (MDCS)	Netherland	Van Balen et al.	1995–Now
	Monument Damage Ontology (Mondis)	Czech Rep.	Caccioti et al.	2013–2015
International practice	Faith in Maintenance - Maintenance Co-operatives Project (FiM/MCP)	United Kingdom	SPAB	2007–2017
	Caring for your Home (CYH)	United Kingdom	IHBC	2016

Reabilitação de Edifícios Antigos. Rehabilitation of Ancient Buildings [18] is one of the publications most used by Heritage professionals in Portugal [14]. It was first published in 2003 and reissued in 2011, with the main goal of "contribute (…) to make a more efficient and widespread dissemination of information on architectural heritage" [18].

This technical publication gathers the main building defects, possible causes and intervention criteria. It is oriented to intervention in ancient buildings, defined as those "built before the advent of concrete (…) thus resorting to traditional materials and technologies" [18].

Método de Avaliação do Estado de Conservação (MAEC). Between 2003 and 2010, the National Laboratory of Civil Engineering (LNEC) developed different methods to evaluate the building' state of conservation, aiming to "support the implementation of public policies for the rehabilitation of building stock" [19]. The Method of Evaluation of the State of Conservation of Buildings (MAEC), although not specifically developed for use in buildings with a heritage value, is highlighted by Portuguese professionals in the rehabilitation sector [14].

It is a legal instrument that includes an inspection form and a supporting glossary. Its application is mandatory only under the Portuguese Urban Renting Regime [20], to determine the updating of the value of rental agreements.

Monument Diagnosis and Conservation System (MDCS). MDCS is an expert system oriented to Heritage professionals, "meant to furnish a support during inspection aiming at assessing the type and severity of the damage found" [21].

It is the latest version of a project started under an European program for R&D in 1993 [22]. Initially called Masonry Damage Diagnosis System (MDDS), it was aimed at "bridging the gap between scientific information and application of it in the field of architectural conservation" [23]. It brought together uniform terminology for the types of damages and theirs origins, and created the possibility of their identification through a computerized questionnaire of a diagnosis system, currently accessible through an online website [24].

Monument Damage Ontology (Mondis). Mondis is the result of a project funded by the Ministry of Culture of the Czech Republic, between 2012 and 2015, "aimed at enhancing data sharing and access, and integration of existing digital systems" [25] in the field of immovable cultural heritage.

Consists in a series of tools oriented to the introduction, edition and consultation of information by professionals. Its aim was to ensure "user accessibility, the reliability of contents and possibility of integrating other information systems already existent in the domain" [25]. However, after the end of the project the online platform is no longer available [26].

Faith in Maintenance – Maintenance Co-operatives Project (FiM/MCP). When William Morris 1877 exalted the need for a culture of preventive maintenance of monuments in 1877 [27], he launched the Society for Protection of Ancient Buildings (SPAB), in the United Kingdom. As one of the most important international associations in Build Heritage safeguard [28], SPAB promoted in 2007 the project Faith in Maintenance (FiM), aimed at safeguarding religious buildings, followed by the project Maintenance Co-operatives (MCP) [29].

To contribute to "more systematic informal inspections and routine maintenance of places of worship" [30], these projects developed an online toolkit with resources for the non-professional community such as baseline survey templates, instructions for assessment and a glossary of historic buildings terminology.

Caring for your Home. This is an online platform aimed at homeowners of traditional buildings, defined as "those built using local, indigenous building materials by craftsmen" [31]. Developed in 2016 by the Institute of Historic Building Conservation (IHBC), this tool is "intended to explain why maintenance is so worthwhile and help owners to look after their homes" [31].

It gathers information on the characteristics of traditional buildings, with instructions for periodic inspections, as well as recommendations for maintenance interventions.

3.2 Comparative Analysis

The tools described above were analysed comparatively, as presented in Table 2.

Table 2. Comparative analysis of key-parameters.

Tool	Support	Format	Type	End-user	Stage
REA	Book	N/A	Ancient buildings	Practitioners	Anamnesis
MAEC	Law-decree	Checklist	Rented properties	Practitioners	Value assessment
Mondis	Mobile app	Form	Monuments	Practitioners	Anamnesis
MDCS	Online platform	Questions	Monuments	Practitioners	Anamnesis
FiM/MCP	Online toolkit	Questions	Places of worship	Wardens and caretakers	Periodic maintenance
CYH	Online toolkit	Checklist	Traditional buildings	Building owners	Periodic maintenance

Support. In the last decade, it was possible to verify the use of digital technologies as a tool to help professional practice. There are different approaches and levels of digitalization: totally digital systems; systems based on the dissemination of information in digital media and non-computerized systems.

MDCS and Mondis are fully digital systems, based on the automation of information in databases. REA is the only fully non-computerized tool, among the analysed ones.

FiM and CYH make information available online, even though the procedure relies mainly on filling in paper forms (not automated). Also, the MAEC can be considered in this group, since although it is published in a law-decree, the support documents are available online and accessible in PDF format.

Format. Considering how the information is structured, it was possible to distinguish three approaches: checklists, forms and questionnaires. The REA does not provide any practical tool to support inspection, so this field was considered not applicable.

The checklists include predefined lists that guide the sequence of procedures to be adopted in situ. However, the ability to identify and describe anomalies dependent on the user's technical skills. In computerized forms, such as Mondis, this problem is minimized by limiting the user to the selection of standardized possibilities, depending on materials and building elements. It also has the advantage of providing specific information for each case, during the inspection.

The questionnaire format is the most effective to eliminates the inspector's subjectivity, as evidenced in the MDCS expert-system. It determines the anomaly through objective and closed-ended questions (Yes or No answers) that consider only the visible reality and not the user's technical knowledge in formulating hypotheses.

Type of Building. The majority of the analysed methods are oriented to the inspection and diagnosis of the state of conservation in buildings with heritage value. The main exception is the MAEC, "designed to be applied to buildings of any construction period" [19]. For the adaptation of the method to historical buildings, Pedro et al. [19]

suggest that inspection parameters should also consider "the heritage value of each functional element". However, the way of doing so is not clearly defined.

End-User. It was possible to distinguish two different approaches to the end-user: tools aimed at the technical community - expert systems - and tools directed to the non-technical community – toolkits.

The second group goal is to "enhance the skills expertise and personal development of volunteers" [30] in Heritage preservation.

In the tools of the first group, there is a concern to make inspection procedures accessible in everyday professional practice, as expressed by Van Balen [23]: "technicians, architects, engineers should be helped in executing correct analysis of the major part of (simpler) damage cases".

Stage of Intervention. The analysed tools can be used during the anamnesis and the periodic maintenance. Anamnesis designates the stage of investigation and diagnosis that must precede any intervention in Built Heritage. It consists in the collection of information "on the structure in its original and earlier states, on the techniques that were used in the construction, on the alterations and their effects, on the phenomena that have occurred, and, finally, on its present state" [6].

The tools developed to support periodic maintenance are aimed at "a set of simple but effective tasks" [32], that "carried out on a regular basis can safeguard the condition of a building" [31].

This classification does not, however, invalidate that the same tools can be used in different phases of rehabilitation processes, whenever they are needed to support decision-making.

Outputs. Each analysed method results in different types of information for the user: defect diagnosis, summary of condition, priorities' weighting and possible solutions, as shown in Table 3.

Table 3. Outputs of each tool.

Tools	REA	MAEC	Mondis	MDCS	FiM	CYH
Support defect diagnosis	X	X	X		X	X
Automated defect diagnosis				X		
Summary of the condition		X			X	
Priorities' weighting			X		X	X
Possible solutions	X		X			

The diagnosis of the identified damages can be supported by complementary literature, through glossaries, such as REA technical book or the MAEC support glossary. In the case of *Mondis* and *CYH*, the identification of defects is supported by predefined lists associated with the different building elements.

With a different approach, the MDCS expert-system automatically determines the defect identified - not depending on the technician's subjective judgment capacity.

The MAEC and FiM/MCP tools allow obtaining a summary of condition of each building element's state of conservation. Also using the weighting factors, the Mondis, FiM/MCP and Caring for your Home tools make it possible to prioritize conservation interventions.

Some diagnosis tools purpose possible interventions to solve the identified problems, through complementary literature (such as REA) or through computerized knowledge matrixes that relate causes and remedial actions (such as Mondis).

4 Discussion

The analysis recognizes some available tools to support the professionals in the inspection and diagnosis of the state of conservation of ancient buildings. It confirms that "while in building rehabilitation, each case is a unique case, the majority of occurrences of defects in non-structural elements can be solved in a systemic way" [17].

Unlike some of the Building Inspection Systems previously analysed by Ferraz et al. [17], the systems analysed in this research have in common the aim of developing practical tools capable of communicating scientific knowledge to daily practice. The methodologies developed by the English conservation associations (SPAB and IHBC) are the most illustrative: due to its simplified structure and accessible language they are "an effective support system in order to provide readily and freely accessible information across the range of media to assist volunteers" [30]. They evidence that it is possible to systematize tools that are sufficiently expeditious to perform inspection of the state of conservation to support decisions, even with few economic resources and little availability of time – the two main reasons pointed out by professionals in Portugal to not perform this procedure [14]. The conclusions of the Maintenance Cooperatives Project point to "an increased community awareness of the importance of maintaining historic places" [33], that may lead to "a shift toward maintenance type interventions on historic buildings instead of more 'heavy' restoration interventions" [23].

The tool MDCS was at the beginning of the project considered "very innovative", for being intended "to develop through scientific research a useful tool directed to possible end-users" [23]. This tool differs from other Building Inspection Systems analysed by Ferraz et al. [17], which, despite providing an online diagnosis, depend on the analysis of "experts in building pathology and rehabilitation" without "an actual visit from an engineer to the building" [17]. Although they support the pre-diagnosis of the building's condition, these tools are not real expert systems, understood as the transposition of "expertise into a computer system" [23].

Despite the growing interest in the computerization of systems, this is not yet a reality. Digitalization is often based on the provision of static online information or complementary tools, but not the entire method: "pathology catalogues are accessible through a website", and contribute to a greater dissemination of information, but are not enough "to provide users with an expedited solution to their needs" [17]. In other cases, despite the initial investment in the development of the systems, they still do not reach the professionals because of insufficient disclosure or lack of commercialization.

Most of the methods are based on the structuring of data in glossaries that support the filling of forms or checklists. The subjectivity of the decisions based on the individual knowledge of the technicians is one of the most evident concerns in the tools analysed. The questionnaire format contributes most to the objectivity of the results, but the forms with automated filling of standard fields have the advantage of making data more easily accessible in on-site operations, adapted to the circumstances and immediate needs of technicians.

The tools most used by Portuguese professionals - REA and MAEC - are still mostly non-computerized, explaining the difficult access to information and the poor efficiency identified in the research and learning process by the technicians [14]. Nevertheless, such tools [18, 34, 35] remain the only ones adapted to the reality of ancient buildings in Portugal, and that is why the professionals interviewed are positive about finding the information they seek in these databases [14]. Crossing the information in these databases with advanced models identified in the literature [24, 25], would make research and learning more effective and reduce the gap in technical knowledge [14]. It would be possible to improve the accuracy of inspections without significantly increasing the complexity of the procedures: maintaining the predominance of photo-assisted visual inspection, without intrusive techniques or costly equipment and procedures.

One of the most critical points for professionals is that inspection has no impact in the project results [14]. By including the possibility of weighing the priorities of intervention as well as information on the possible conservation actions to be taken for each damage, some of the tools analysed are useful to support decision-making, being adequate answers to the concerns expressed by the practitioners.

5 Conclusion

The purpose of this study was to make a comparative analysis of different methods of inspection and diagnosis for the Built Heritage. The literature review identified different approaches to the subject: databases, law-decrees, computerized expert-systems and toolkits for the non-technical community. In common, these tools rely on visual, expeditious and cost-effective inspections.

Databases and glossaries are not sufficient to support in situ procedures. Checklists, forms, and questionnaires can be used during the fieldwork to guide the technicians and reduce the subjectivity of the inspection.

To Implement the technical expertise in computerized systems favours the dissemination of information and its real time real time accessibility, and allows for more rigorous evaluations, less dependent on the user's individual experience. Linking these systems with information about intervention priorities and remedial solutions makes them decision support tools.

This paper demonstrated that the main problems pointed out by practitioners in previous studies (expensive, time-consuming, inconsequential procedures and dispersed information) can be solved by structuring information in computer systems. However, this is only valid if these systems are adapted to the different geographic contexts and construction periods.

Future research may contribute to the development of a methodology that brings together the added value identified in the different models, consolidating a tool that allows in a simple but objective way to diagnose the state of conservation of buildings with heritage value and to support the decision-making regarding the intervention.

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